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CONTROL OF AQUATIC GROWTHS IN RESERVOIRS BY COPPER SULFATE AND SECONDARY EFFECTS OF SUCH TREATMENT

by Ray L. Derby and D. W. Graham

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CONTROL OF AQUATIC GROWTHS IN RESERVOIRS BY COPPER SULFATE AND SECONDARY EFFECTS OF SUCH TREATMENT

By Ray L. Derby[1], Member, A.S.C.E., and D. W. Graham[2]

Synopsis

Continuous feeding of copper sulfate at a rate sufficient to maintain an 0.8 to 1.0 part per million copper sulfate residual has been found to minimize pondweed and plankton problems in open reservoirs. The residual copper remains toxic to aquatic growths for longer periods than commonly believed and will affect biological activity further down the system and for as long as four months. Subsequent to the start of residual treatment, a sharp decrease in characteristic earthy-musty odors was noted throughout the system. This is believed due either to direct inhibition of some phase of the metabolic processes of odor producing micro-organisms, or to the decrease of their food supply to such an extent that an insufficient number of organisms develop to create an odor nuisance.

Introduction

The Los Angeles Department of Water and Power has 26 open reservoirs having a total capacity of about 400,000 acre feet (130 billion gallons) and ranging in individual capacity from 9.4 to 183,500 acre feet. They are located over a large area with widely diverse climatic and topographic conditions at distances up to 350 miles from Los Angeles and at elevations from 378 to 7,130 feet.

A schematic flow diagram of the reservoirs pertinent to this study is shown in Fig. 1. Needless to say, a wide variety of biological problems are encountered under such varied environmental conditions.

The presence of Potomogeton panormitanus and Zannichellia palustris, commonly called duckgrass or pondweed, in many of the reservoirs of the Los Angeles Department of Water and Power is a detrimental factor in their operation and in the quality of the water supply. Growths start about March 1st in Southern California and under favorable environmental conditions will develop around the perimeter of reservoirs to depths of 25 feet or more. These growths give the reservoir an unsightly appearance, act as algae seeding harbors, and attract waterfowl which contribute a heavy pollutional load to the water supply. In the late summer and fall, the pondweed breaks off and clogs the outlet screens or piles up on the leeward sides of the reservoir causing a difficult operational problem. It also sloughs off and decomposes, thereby contributing to the organic load and adding to the taste and odor problems of the supply.

Exact identification of the individual species of pondweeds may be quite difficult, but the distinguishing characteristics of Potomogeton and Zannichellia are such as to facilitate their identification. Submerged Potomogetons

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generally have long, slender leaves which are alternately placed on the stem. The plant produces erect flowering spikes, usually at the stem terminals, which may rise above the water surface for wind pollination. The flowers mature to form small beaked "nutlets" or fruit about the size of air rifle shot. Zannichellia differs from Potomogeton by having slender leaves oppositely placed on the stem. The fruit is characteristic in forming small clusters of "pea-pods" at the junction of the leaves and the stem, generally at the lower portions of the plant. The fruits are in groups of 2 to 5 and vary from 2 to 2.5 mm in length. The fruit is also distinguished by the presence of teeth along one edge, and the flat pea-pod shape. A diagram (Fig. 2) indicates the characteristics of each plant.

Pondweed Control Before 1949

Many methods of pondweed control have been tried out through the years and found to be ineffective or impractical for a domestic water supply. Mechanical methods tried included the use of a mechanical saw tooth cutter and the dragging of heavy cables along the reservoir bottom. Chemical methods are limited by taste and odor considerations and by toxicity. Chlorinated hydrocarbons, solvent naphtha, and sodium arsenite, which are reported as satisfactory for use in irrigation ditches and other non-potable waters were determined to be unacceptable for a domestic supply. Two methods which do give satisfactory, though temporary results, are lowering the water stage or emptying and periodic cleaning of the reservoir. In larger reservoirs drawing down the water level for a month or more and allowing the plants to become thoroughly dry accomplishes the same end. Unfortunately, this is often not practical and other methods of control must be looked for.

In 1948 it was decided to try a series of experimental treatments with copper sulfate. This chemical had been used for many years for the treatment of excessive plankton growths but had never been tried in controlled experiments against pondweed. From plankton treatment experience it was known that periodic applications of from 0.1 to 0.5 ppm* would not affect pondweed so it was decided to attack the problem from two different angles; first, periodic heavy treatments of shallow coves and second, residual treatment of an entire reservoir.

Experimental Treatment at Lower Hollywood Reservoir

The pondweed problem was particularly acute at Lower Hollywood Reservoir, and six coves were selected for treatment with either snow or lump copper sulfate. An extremely heavy (and uneconomical) dosage of 100 parts per million was used on the assumption that if this amount worked, smaller doses could be used until the lowest effective quantity was reached. Treatment in the selected coves on a monthly, bimonthly, and trimonthly basis, was initiated in March of 1949 and continued through September when most of the untreated pondweed in the reservoir had begun to decompose. In spite of the heavy dosage pondweed succeeded in growing, and some plants reached lengths of twelve feet. Some injury and stunting of growth was produced, especially in the shallow sections of the coves; but the general over-all results of all

*Throughout this paper, concentrations are reported as parts per million of copper sulfate pentahydrate, $CuSO_4 \cdot 5H_2O$, which is the form in which copper is ordinarily applied to reservoirs. This material is also commonly called "bluestone" and has a copper content of approximately 25 per cent.

treatments were insufficient to justify the cost, and the method was discarded as impractical.

Residual Control Experiments

Residual control is defined, for purposes of this paper, as the practice of adding copper sulfate in such quantity as will furnish a specific copper residual (by chemical analysis) at some remote point or at some future time. Very little, if any, work has ever been done on this subject. A review of the literature for the past 50 years will tend to discourage one from even trying it. The consensus of expert opinion, as found in the water works literature, is summed up in the American Water Works Association manual "Water Quality and Treatment (1950)"[1] as follows:

"With respect to copper sulfate, it may be pointed out that when that chemical is left free in water, it reacts with calcium bicarbonate to form calcium sulfate and basic copper carbonate. The basic copper carbonate may then be decomposed into copper hydrate and carbonic acid. Both the carbonate and hydrate have very low solubilities; and in a hard water the carbonate may be almost instantly precipitated, the subsequent decomposition into the hydrate requiring a longer period."

". . . insoluble copper carbonate is precipitated from the water to which it is applied--immediately in the case of most waters; more slowly, but still long before delivery, in a very soft water."

Physiological Considerations

Whenever any foreign material is added to a potable water supply, questions are raised as to physiological safety. Much work has been done on the subject of the toxicity of copper, and the limit approved by the U.S. Public Health Service in 1946 is 3.0 ppm. Since only 1/4 of the copper sulfate molecule is copper, this would permit the addition of 12.0 ppm copper sulfate before the limit is exceeded, even if it all reaches the consumer.

Actually, in the case of copper, the quantity present in most natural waters is insignificant. The major source of copper intake in the human body is food; many varieties of which contain appreciable concentrations. Normal diets may provide as much as 2 mg a day which is approximately ten times as much copper as is required for nutritional purposes. Study has proven that no adverse physiological effect is noted unless the intake exceeds approximately 100 mg per day. If a person were to drink as much as 8 quarts of water a day which contained as much as one part per million of copper sulfate (0.25 mg copper), the total daily intake from this source would only be 2.0 mg.

Residual Control Experiments at Girard Reservoir

Girard Reservoir, a 40 acre-foot balancing reservoir, was selected for the first experiment. It has a uniform depth of 20 feet and a dirt bottom. The reservoir was drained and cleaned in July of 1948; and when it was refilled, sufficient copper sulfate was added to provide an average residual of 4.0 ppm copper sulfate. The initial hardness and alkalinity expressed as calcium carbonate was 92 and 138 ppm respectively. The copper residual was maintained by periodic scattering of copper sulfate snow over the reservoir from a boat. Treatment was discontinued after the first of September and thereafter the copper sulfate residual fell off gradually until, by January 1st, it was down to 0.5 ppm.

Discovery of new heavy growths the following May showed that a relatively high residual for approximately two months would not eliminate the pondweed, and it was decided to try a smaller dose over a longer period of time. Accordingly, 1.0 ppm copper sulfate was added in May, 1949, and the residual was maintained between 0.8 and 1.0 ppm until October, 1952. The pondweed had reached a height of from 2 to 4 feet when the treatment was started. After about two weeks the tips began to turn brown and growth stopped. By summer the stalks had been completely covered by a zoogloeal slime and had fallen to the bottom. No pondweed grew in Girard Reservoir from this time through October, 1952, when the treatment was stopped. It will now be interesting to find out if the growth returns this spring (1953), or if 3-1/2 years of continuous treatment was enough to eliminate the roots as well as the tops. The amount of copper sulfate required during this 3-1/2 year period was 1,030 pounds or an average of 35 pounds per month. This relatively small quantity indicated that copper did not precipitate as rapidly from an alkaline water as the literature would lead one to believe. The cost of treatment chemicals during this entire period was less than $100.

The residual treatment was not an unmixed blessing, however. The continued use of copper sulfate reduced the planktonic algae in the reservoir to one predominant species, a tiny spore form, probably of Phormidium. This organism persisted in large numbers until the treatments were discontinued. During this period, the transparency averaged about 4 feet, and the water had a distinct greenish cast. The predominant odor, averaging about a III intensity, was a musty, moldy, and grassy type usually associated with Cyanophyceae. After treatments were discontinued in October, 1952, the spore form almost disappeared while Navicula, Phormidium, and Raphidomonas flourished for a while, then gradually died off. During this time the appearance, transparency, and taste and odor of the water gradually improved.

It seems apparent that this type of treatment, though successful in controlling pondweed, did not benefit the general quality of the water in this particular reservoir.

Solution Feed Equipment

The successful outcome of the experiment at Girard Reservoir during the summer and fall of 1948 encouraged the addition of Lower Franklin Reservoir to the experimental list during the spring of 1949. Continuous solution feed was used in this and in subsequent installations. Details of the equipment are shown in Fig. 3. The unit consists of a redwood tank of sufficient capacity to hold a 5 to 6 days' supply of copper sulfate. This permits the operator to visit the installation on a semi-weekly basis. On each side of the tank a 4" x 6" perforated box is constructed to serve as a screen for the water flowing through the tank. The water supply is furnished by a constant level tank, and the flow regulated by an adjustable outlet. All pipe fittings are plastic or hard rubber. The water level is maintained in the bottom of the redwood tank at a depth of twelve inches. The rate of feed is determined by the flow through the tank, and the concentration of the copper sulfate solution is dependent on the temperature.

A few difficulties have been encountered. Metal hoops and fittings on the tanks, although protected by paint, have been subject to corrosion and have required occasional replacement. A copper carbonate deposit tends to clog the outlet line, and an additional water supply is required to keep this line flushed to reduce the number of periodic cleanings required. Insoluble impurities in the copper sulfate leave a deposit in the bottom of the tanks,

necessitating seasonal cleaning. In general, however, the units operate efficiently with a minimum of servicing and maintenance.

Residual Control at Lower Franklin Reservoir

Lower Franklin Reservoir has a capacity of 1,030 acre feet, an average depth of 32 feet, and normally develops heavy growths of pondweed along its banks. Unlike Girard Reservoir, this reservoir has a relatively rapid theoretical turnover rate of 6.1 days. Because a series of submerged inlets extend about 3/4 of the length of the reservoir, some of the incoming water will actually leave the reservoir within a few hours. Copper sulfate was added by solution feed at the inlet from April until October, and a residual of 0.8 to 1.0 ppm at the outlet was successful in holding growths to a foot or less during 1949 and 1950. In the spring of 1951 the reservoir was operated at a low stage for several months to allow work on a by-pass line. This exposed the pondweed to the sun and it dried out. The reservoir was returned to its normal level on October 15th, and no fresh growth was found up to March 1952. This was primarily due to the drying up of the plants rather than to the effect of the copper sulfate, although a contributing cause may have been the failure of the treated plants to produce seed and tubers.

Residual Control at Pressure Break Reservoir

Pressure Break Reservoir has a capacity of 111 acre feet and an average depth of 15 feet. It is relatively shallow, with a mud bottom and asphalted banks. Pondweed growth, previous to continuous copper treatment, was a major problem. Former pondweed growth and removal were described by the reservoir caretaker as follows: "The pondweed grew all the way across the bottom of the reservoir, sending up long stems to the surface. Along the bank there was a dense growth of tangled pondweed. During the spring and summer, the mornings were spent removing floating plants. When the growth was mature and breaking loose, the entire day was spent removing plants and carrying them away. The usual procedure was to thrust a long bamboo pole into the thick growth of pondweed and twist it onto the pole. Then the catch was pulled out on the bank. When the plants became a serious water quality problem, machinery and extra men were brought in. A winch was rigged up on the bank with a long cable fastened to an anchor on the shore. The loop of the cable was layed out in the reservoir. When the cable was pulled in, the plants came with it. The crew would clear the cable and repeat the process, moving about the edge until the reservoir was clean."

A small continuous-flow copper sulfate feeder was installed in April of 1949, and the residual maintained at 0.8 ppm at the outlet. The pondweed, already 6 to 12 inches in height, never matured. Its greatest height was in August when it reached 14 to 18 inches. The copper destroyed the green pigment in the leaves and stems giving a burned appearance. Various microorganisms, immune to copper, attached themselves to the plants, covering them with a gelatinous coating. In September, the plants were overburdened by the gelatinous sheaths and broke down. The only green left was in the plant nodes near the roots. Microscopic examination of the sheath showed a framework of Oscillatoria or Phormidium filaments in which Microcystis-like spheres filled in the spaces. Some Anabaena chains found deep in the mass indicated the protective properties of the sheath against copper. Treatment lasted from April 18th to October 2nd and required 9.1 tons of copper sulfate at a cost of $1,400.

Residual Control at Dry Canyon Reservoir

By April of 1950, experimental work at the smaller reservoirs had shown sufficient success to warrant construction of a large scale installation designed to treat the entire aqueduct flow, which averaged about 460 second-feet during the treatment period. Dry Canyon Reservoir itself is only a "wide spot in the aqueduct". It is about 3,500 feet long, averages about 500 feet in width, has a capacity of 751 acre feet, and a mean depth of 13 feet. Pondweed grows profusely during the summer and forms unsightly masses over much of the lake surface. Here again, outlet screens had to be constantly freed of broken stringers, and tastes and odors increased perceptibly from inlet to outlet even though the theoretical retention time was only 0.79 days.

On April 14, 1950, a continuous feed of copper sulfate solution was started at the inlet of Dry Canyon Reservoir. This was regulated to maintain a residual of approximately 0.8 ppm of copper sulfate at the outlet. The immediate effect of this treatment was to stop further growth of pondweed which had already reached a height of 3 feet. Deterioration of the plants was a gradual process, taking most of the summer. At first, some loss of the bright green of the leaves and some browning was noticed. Then green slimy growths gradually covered the plants and weighted them to the bottom. These slime growths were largely bacterial in origin and contained many blue-green algae such as Phormidium and Oscillatoria. The pondweed plants were never completely dead during the summer, as the slime could be stripped from samples taken and green leaves found underneath. New plants were also continually trying to grow, only to deteriorate as described. However, these new growths were not very prolific, being found only as a few scattered plants in the areas sampled. Their presence, though, indicated the need for continuous treatment during the growing season, for underground stems, tubers, and seeds were obviously not killed.

Toward the end of the summer the green, slimy mat had formed over the bottom of the shallower areas of Dry Canyon Reservoir. This mat now began to peel off in pieces up to three or four feet in diameter and to float around in the lakes until caught in the screens or washed up along the shore line. They were unsightly and caused some trouble, but not nearly as much as was caused by the vast masses of pondweed in previous seasons. After maintaining a residual of 0.8-0.9 ppm at the outlet for the first three months, the residual was dropped to 0.6 ppm for the remainder of the season. Treatment was continued until October 2nd and 165 tons of copper sulfate were used at a total cost of $25,000. In 1951, 241 tons were used from March 13th to October 22nd, at a cost of $41,000, while in 1952, 215 tons were added from March 28th to October 22nd at a cost of $41,500. (Costs are based on prices for copper sulfate of $151, $170, and $193 a ton for 1950, 1951 and 1952, respectively.)

Effect of Copper Residuals on Secondary Aquatic Plants

Although copper sulfate appears to be most successful in the control of Potomogeton panormitanus and Zannichellia palustris, it has had a little effect on other aquatic plants found in our reservoirs. A few species of plants, enjoying freedom from competition with the pondweed in the shallow marginal areas, have actually thrived in the new environment. This is especially true of several types of rushes of which Eleocharis is the most persistent. This rush forms a carpet of short compact growth in the shallow mud

or silt, and in the fall may peel off in large masses requiring removal from the outlet screens. However, this happened infrequently and was of small concern as compared to pondweed troubles. The larger forms of rushes present at the margins of Dry Canyon Reservoir were unaffected by the copper treatment. A few cattails and tules that managed to get a start at the margin grew vigorously and showed no injury from the copper present.

Effect of Copper Residuals on Reservoir Fauna

The copper residual during the treatment period had a marked effect on the aquatic environment as far as the fauna of the reservoir was concerned. The elimination of some varieties of fishes may be directly traced to the toxic action of copper. A concentration of 0.8 to 1.0 ppm copper sulfate was lethal to suckers and carp. Some carp survived at the more distant reservoirs where time had evidently reduced the quantity and toxicity of the copper. Apparently most buffalo withstood the treatment, as only a few of this species were found dead during the period of treatment. The spiny-rayed game fishes (black bass and bluegill) took the copper in stride with only a slight increase in mortality. It is doubtful that trout could have survived such concentrations.

There has been a marked decrease in the reproductive capacity of fishes in both close and distant treated waters which has resulted in a definite decline in the fish population. This is undoubtedly due primarily to the reduction of the food supply which is caused by the adverse effect of copper on both plankton and the larger plankton-feeding organisms.

The paper-shelled mussel (Anadonta) was another type of organism that succumbed to the copper treatment. Hundreds of these large bivalves were killed at Dry Canyon Reservoir and produced a disagreeable taste and odor problem for a short period of time. These shellfish are present in Haiwee and Fairmont Reservoirs, but their presence in any quantity at Dry Canyon Reservoir was not suspected until the treatment made their numbers obvious.

The numbers of migratory waterfowl stopping at reservoirs has been greatly reduced due to the scarcity of pondweed (duckgrass). Birds which usually remained for weeks, now continue their flight after an overnight stop.

Effect of Copper Residuals on Plankton

As might be anticipated, the plankton population declined markedly in reservoirs subjected to continuous copper sulfate treatment, and also in reservoirs fed by the treated waters. In the last three seasons of continuous-flow copper treatment, regular seasonal growth-patterns have developed, which are different for each reservoir. In general, diatoms are predominant in the spring when copper feeding is started. Stephanodiscus, Melosira, and Asterionella are the first to drop out. Navicula and Synedra persist in diminished numbers and spore counts increase. Few plankton are produced in April, May and June. In July, plankton varieties and numbers increase with the temperature, and peak counts are recorded in August. September production is still high, falling off in October. The growth of plankton appears to increase with rising temperatures. Varieties of plankton are largely determined by the amount of copper present.

There is little evidence that new species are coming into the seasonal pattern; rather, certain resistant common plankters, unopposed by normal competitors, have increased their numbers. Fig. 4 shows the average diatom count in areal standard units for two fiscal years preceding residual treatment and for two years during residual treatment at six of the reservoirs.

The declines in all but Lower Franklin and Pressure Break Reservoirs reflects the benefits of treatment at Dry Canyon. In the case of Lower Franklin and Pressure Break Reservoirs, additional local residual installations were used during part of the treatment period as previously outlined.

Similar studies of the Cyanophyceae group indicate that the effect of the copper was insignificant. A slightly higher count was generally noted with the Chlorophyceae group, which was almost entirely composed of zoospores in varying stages of motility and non-motility. Due to their minute size, these micro-organisms have more dispersion area for light than an equivalent concentration of diatoms and thus cause increased color and turbidity. Fortunately, they grow close to the surface so that they were not a difficult problem in deeper reservoirs having proper gate elevations. However, the color and turbidity in the shallow reservoirs such as Girard and Pressure Break increased over prior years.

Effect of Residual Treatment on Tastes and Odors

Earthy-musty tastes and odors in the aqueduct water reach maximum intensity in September. Prior to 1949, this condition was especially noticeable in Lower San Fernando Reservoir and many complaints were received from consumers. From 1947 to 1949 an intensive biological study was made to determine the causes of this condition and it was concluded that the local problem was not due to taste and odor producing algae, but rather to the bacteriological decomposition of organic matter in a favorable environment. It was tentatively concluded that the main factors favoring this undesirable bacteriological activity were excessive algae production from within the reservoir and excessive amounts of other organic material washed into the reservoir by storm waters from without. The latter included runoff from pasture land and farming operations, in addition to leaves, brush, and other organic debris blown and washed in by storms. Environmental factors favoring this biological activity include shallow areas and elevated temperatures.

Although it was anticipated that the residual copper sulfate treatment at Dry Canyon would reduce the organic load due to algae in Lower San Fernando Reservoir to some minor and unpredictable extent, the remarkable reduction in taste and odor which actually took place was entirely unexpected. As summer progressed (1949) it became apparent that the earthy-musty tastes and odors were greatly diminished in Lower San Fernando Reservoir and that water quality had improved in other aqueduct-fed reservoirs as well.

The same phenomenon occurred in 1950 and September of that year found the biological problem at Lower San Fernando so much improved that the water leaving this reservoir was greatly superior to the inlet water. Further investigation then showed the principal remaining source of taste and odor to be Haiwee Reservoir. This condition held through 1952. This has been very gratifying since it was felt that such success, if attained, would take several years until the accumulated organic load had been consumed. Also, there was every probability that the other sources of organic pollution were in themselves sufficient to support taste and odor production even though the organic load due to algae was materially reduced.

A study was initiated to determine what specific micro-organisms might be responsible for the taste and odor production, and in 1951 an Actinomycete was isolated from Lower San Fernando Reservoir which produced typical earthy-musty odors under laboratory conditions. This was thought to be the solution to the tastes and odor problem, but further work indicated that Actinomycetes were only partially responsible. It now appears that the tastes and

odors are caused by a complex microbiological decomposition of organic material by species related to though not identical with certain organisms which have been reported in the literature. Similar problems caused by Actinomycetes have been reported from Texas[2], Oklahoma[3], and Argentina[4]. The principal differences between the local variety and those reported by others are found in the minimum temperature at which growth occurs and in their reaction to copper sulfate and to chlorine dioxide. Considerably more research appears to be needed in this field.

Recent review of data suggests that the improvement obtained resulted from the reduction of organic material and of bacteria involved in the breakdown of vegetable matter, rather than from bactericidal action on Actinomyces alone. This view is further substantiated by a study in which it was demonstrated that concentrations of copper sulfate up to 10 ppm had no apparent effect upon the survival of Actinomycetes spores of the type isolated from the Los Angeles sources. It is possible, of course, that the residual copper sulfate is inhibiting some phase of the metabolic processes even though sufficient nutrient still remains for the production of tastes and odors under normal environmental conditions.

In view of the success in reducing tastes and odors in Lower San Fernando Reservoir, some consideration has been given to the utilization of residual copper sulfate treatment at the inlet to Haiwee Reservoir. Water from Haiwee Reservoir contributes typical earthy-musty tastes and odors to the supply during September and October. This program would be costly. Haiwee Reservoir has a capacity of 58,500 acre feet, is seven miles in length, 1,804 acres in area and has a theoretical retention time of 59 days. It is estimated the cost of maintaining an 0.8 ppm copper sulfate residual for only six months would require about 360 tons and would cost in the neighborhood of $72,000. Since the tastes and odors from Haiwee are lower in intensity and of shorter duration than those from Lower San Fernando Reservoir, this expensive treatment is not yet considered justifiable. At present Haiwee is treated by broadcasting copper sulfate "snow" over the surface of the lake, when diatoms reach concentrations of 1000 areal standard units. This materially reduces the total organic load on the aqueduct system and is accomplished at an average yearly cost of about $15,000 for copper sulfate.

Retention and Effectiveness of Residual Copper

It is generally reported that copper salts react rapidly in alkaline waters to form insoluble precipitates which settle forever into the bottom muds of a reservoir. While this may be true to an undetermined extent, it has been shown by experience during the past three years that much of the copper will remain either in solution or suspension for many weeks after being added to our supply. Fig. 5 shows the actual time lag between copper residuals at Dry Canyon, Lower San Fernando, and Stone Canyon reservoir outlets. Examination of the chart shows that it actually takes 2 to 2-1/2 months until copper sulfate applied at Dry Canyon reaches its peak at Lower San Fernando outlet. The peak at Stone Canyon Reservoir outlet occurs about four to five weeks later than at Lower San Fernando. Table 1 gives a chemical analysis of the aqueduct water. It would be expected that a water of lower alkalinity or lower pH would retain copper in an active form for a longer period of time.

It has not been successfully determined by chemical analysis whether the copper is present in a soluble or insoluble form, but in view of the marked biological changes which are found in reservoirs remote from the source of copper and at time intervals of up to 4 months, there can be little doubt that

the toxic effect of copper on algae and pondweed lasts longer than has been heretofore reported. Changes in the quantity and character of the plankton population have been marked, and copper sulfate residuals as low as 0.2 ppm inhibit the growth and reproduction of pondweeds to some extent. Each growing season these plants have been diminishing in number and vigor even in the remote reservoirs.

Conclusions

In water of moderate alkalinity, such as the Los Angeles' Owens Valley aqueduct supply, copper remains active longer than generally thought. Aquatic plants such as Potomogeton and Zannachellia can be controlled and ultimately eliminated or greatly reduced by maintaining small residuals of copper. Copper treatment apparently has a beneficial, secondary effect on tastes and odors. The reasons for the secondary effects are not fully understood as yet, but are probably due to reduction in food supply of taste and odor producing organisms and/or a direct inhibitory effect on the metabolism of the organisms concerned.

Submerged aquatic weeds may also be controlled by lowering the water surface and exposing the roots to air for a period of a few weeks once a year. When this can be done, it is the least expensive method, as no material and very little labor is required.

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Table No. 1

Average Analysis of Constituents Pertinent to Copper Precipitation, Los Angeles Owens Valley Aqueduct Water 1951-52.

Specific Conductance (K x 10^6)	324.
Temperature (May through September)	20° C.
pH	8.5
Dissolved Residue	202 ppm
Alkalinity	115 ppm
Hardness	84 ppm
Calcium	25 ppm
Silica	20 ppm

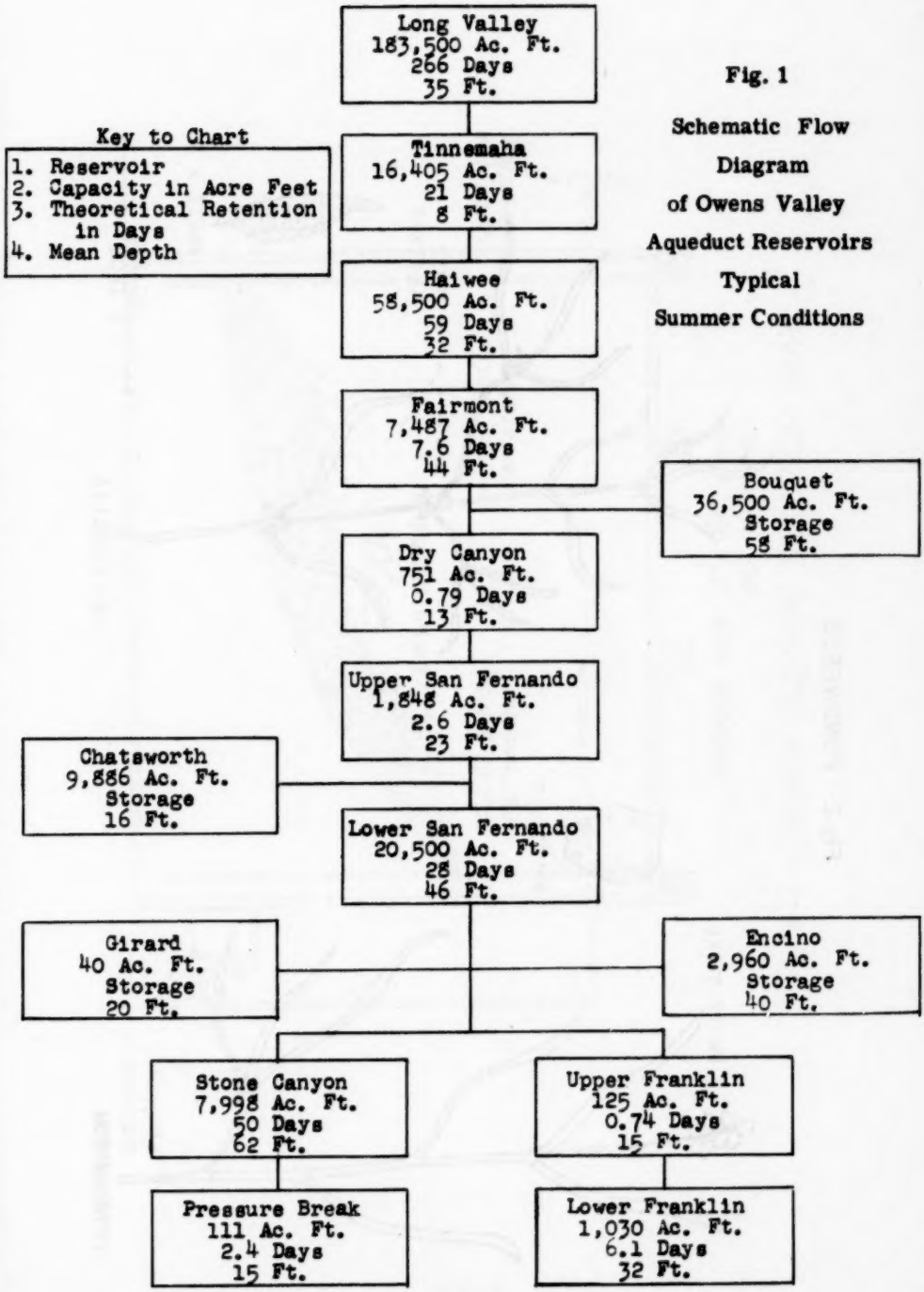
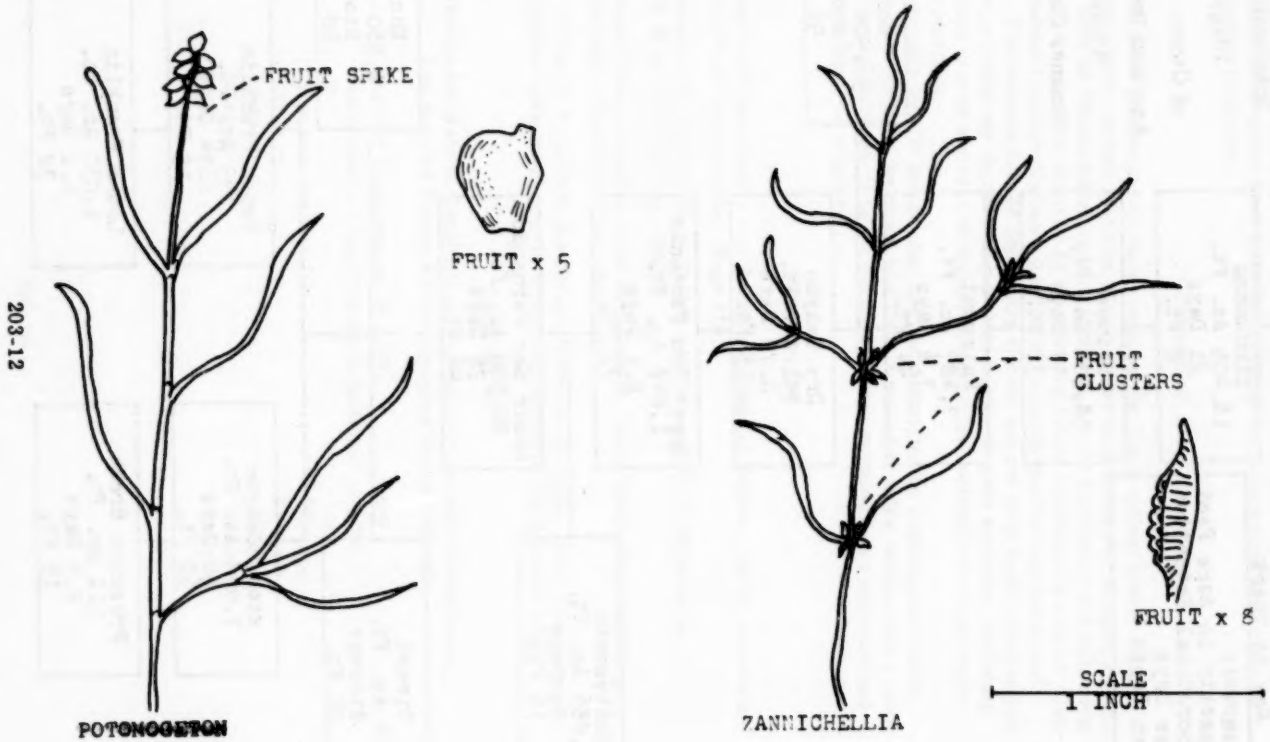


Fig. 1

Schematic Flow Diagram of Owens Valley Aqueduct Reservoirs Typical Summer Conditions

Fig. 2- PONDWEEDS



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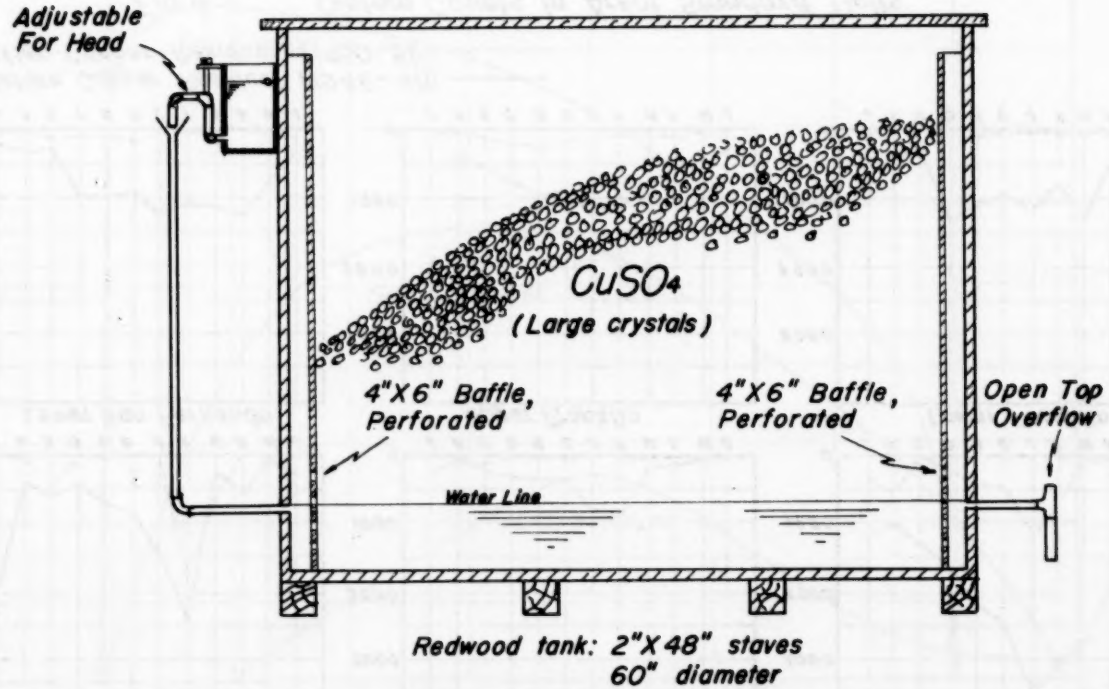

Fig. 3.-- COPPER SULFATE SOLUTION TANK

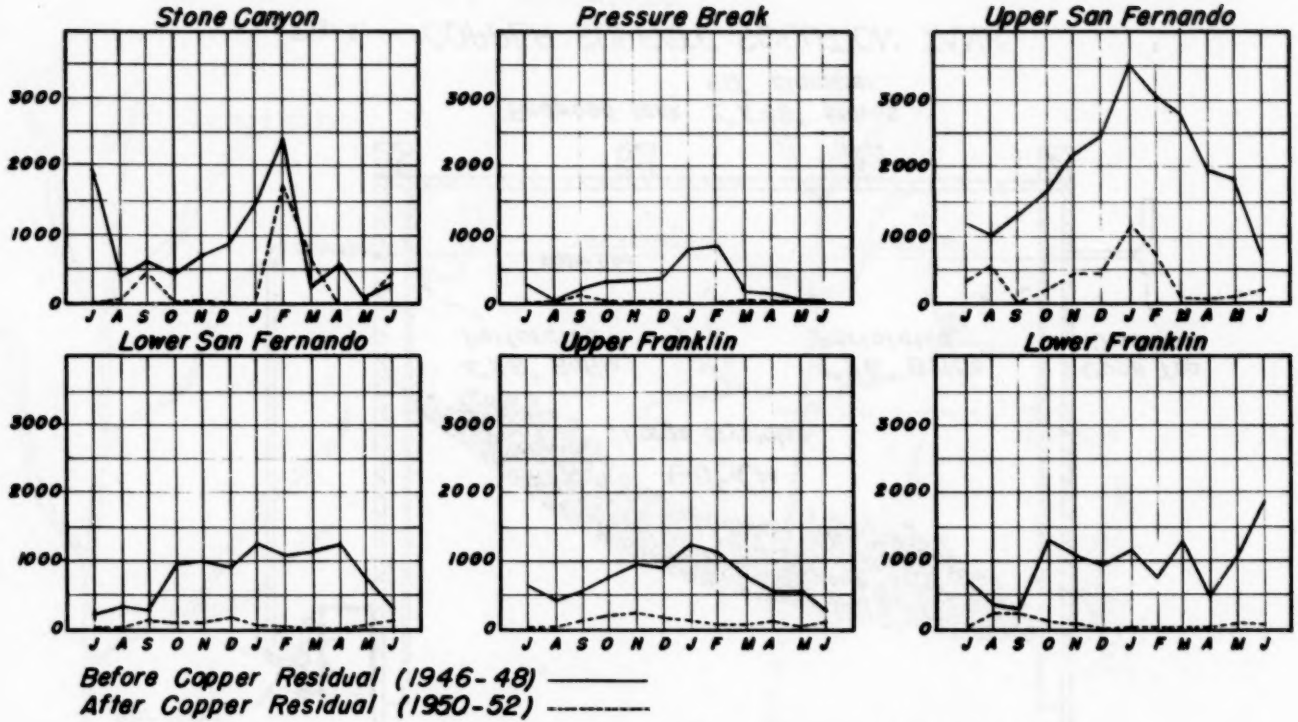

Fig. 4 - Diatom Counts in Areal Standard Units

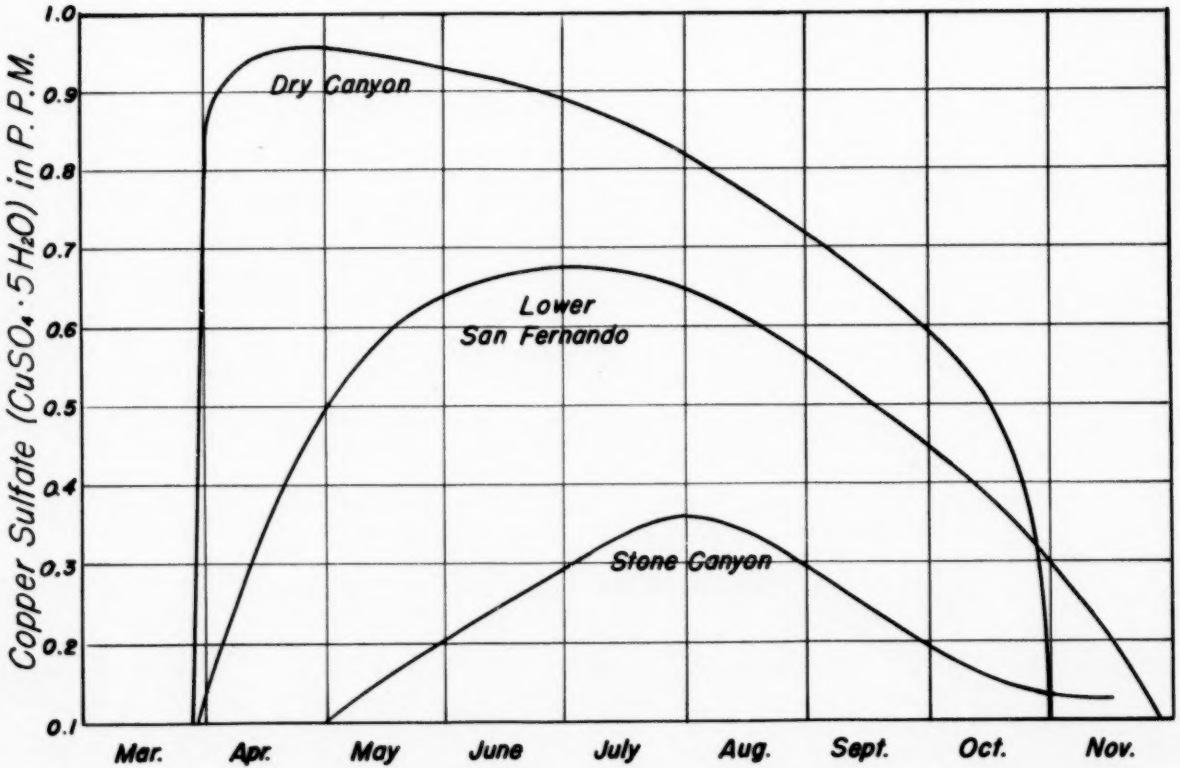

Fig. 5 — Typical Copper Sulfate Residual at Aqueduct Reservoirs

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